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THE DEVELOPMENT OF TRACE: AN INTEGRATIVE BARGAINING PARADIGM FOR INVESTIGATING MULTIDISCIPLINARY DESIGN TRADEOFFS (U)

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FOR THE COMMANDER

Kenneth R Boff

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13. ABSTRACT *(Maximum 200 words)*

This report describes our creation, application, and validation testing of an experimental paradigm -- TRACE (Tradeoffs, Research, and Analysis in Collaborative Ergonomics). Our primary goal in developing TRACE was to craft a framework within which to experimentally probe issues relevant to negotiation and decision making in multidisciplinary design teams. The paradigm was adapted from negotiation research in the area of integrative (win-win) bargaining and was set in the context of an automobile navigation system development project. We hypothesized that if the paradigm reasonably captures the context of real-world multidisciplinary design practice, individuals with actual design experience would perform better than individuals with little or no design experience. Support was found for this hypothesis. In addition, experienced subjects' questionnaire ratings supported the idea that cost/performance tradeoffs, the focus of the TRACE paradigm, are important in design. Future research and applications of the paradigm are suggested

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PREFACE

The work underlying this report was performed by the Armstrong Laboratory, Human Engineering Division, Wright-Patterson AFB, Ohio in support of Work Unit 71841225, Collaborative Systems. The Logicon Technical Services, Inc. portion of this work was performed under contract F41624-94-D-6000.

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INTRODUCTION

This report summarizes a project within the Collaborative Design Technology Laboratory (CDT Lab) -- a component of the Design Technology Branch, Armstrong Laboratory Human Engineering Division (AL/CFHD), at Wright-Patterson Air Force Base (WPAFB) in Dayton, Ohio. The CDT Lab was established to address collaboration in design and its facilitation through information technology. The CDT Lab was a component of AL/CFHD work aimed at realizing Computer Aided Systems Human Engineering (CASHE), as described in Boff, Monk, Swierenga, Brown, and Cody (1991). Broadly speaking, the CASHE "vision" entailed bringing advanced information technology to bear on the task domain of human factors engineering in systems of potentially large scale and complexity. In August 1993, Human Engineering Division management directed CDT Lab "... (to) enable and facilitate distributed group decision making, problem solving, and 'concept visualization' for simultaneous engineering and design."

This report describes our creation, application, and validation testing of an experimental paradigm -- TRACE (Tradeoffs, Research, and Analysis in Collaborative Ergonomics). Our primary goal in developing TRACE was to craft a framework within which to experimentally probe issues relevant to negotiation and decision making in multidisciplinary design teams. Because the background rationale and prospective payoffs motivating this research involve real-world design activities, we were naturally concerned that the TRACE paradigm exhibit *ecological validity* (Brunswik, 1956) -- i.e., fidelity to the real-world application scenario. The ultimate focus of this paper is how our inaugural TRACE results relate to validation of the TRACE task. Before addressing that issue, however, we must first outline our rationale for creating TRACE, discuss the theoretical foundations of TRACE, describe the TRACE task and its construction, and report the conduct and results of the initial TRACE experiments.

In designing systems of scale, individuals with different backgrounds, skills, and areas of concern come together to form a Multidisciplinary Design Team (MDT). This team approach is the essence of the *concurrent engineering* practices currently proliferating throughout the private sector generally and the U.S. Air Force (as *Integrated Product Design*) specifically. TRACE was intended to aid us in studying the human factors of collaborative system design -- i.e., researching the sort of collaborative activities MDTs undertake as a preface to prescribing how best to support them. This requires us to focus on human capabilities and limitations, the nature of the design task, and the contextual and dynamic factors shaping the system design process. TRACE represents experimental research toward better understanding of these issues and more effective tools and procedures for MDTs.

Boff (1987) suggests the overall effectiveness of design depends on successfully leveraging information into design decisions. Frequently technical data that can and should be considered are not integrated into design decisions due to "cross-disciplinary chokepoints" (Boff, 1987). Using participant-observer techniques in ethnographic studies of engineering design, Bucciarelli (1988) characterized design as a social process, emphasizing the role of discourse among multidisciplinary design participants. Decisions made across disciplines can be described as a negotiation among team members who, while sharing common goals at some level, may hold different interests and objectives (Bucciarelli, 1988). Thus, each participant in design may be characterized as negotiating design tradeoffs from a perspective biased by his or her own unique background, expertise, and role within the organization.

Perhaps the most general design tradeoff is that between cost and performance. How much time, money, and effort should one put into a system to enhance its various performance capabilities? In its simplest form, a cost/performance tradeoff entails a dichotomous decision to include or exclude a specific attribute or function into a design. In such a case, multidisciplinary design team members will negotiate for or against such inclusion based on their own expertise or knowledge of relevant technical data. If this expertise or knowledge is shared and understood by

the other MDT members, it could potentially enlighten the discourse, improve decision making, and promote beneficial design tradeoffs (Cody, Rouse, and Boff, 1993). System design can be improved if we better understand how such advantageous tradeoffs are discovered by the MDTs and then support their discovery in the system design process. The following sections will outline how we have pursued this goal by extending prior empirical research.

Integrative Bargaining

Social psychological research in the area of *integrative bargaining* has systematically explored the development of mutually advantageous (*integrative*) outcomes in negotiation, frequently in the context of a role-playing task in which students negotiate as buyers and sellers (Pruitt, 1981; Pruitt & Carnevale, 1993; Pruitt & Lewis, 1975; 1977). In such an integrative bargaining task, the buyer and seller attempt to reach agreement on the price of three appliances: television sets, vacuum cleaners, and typewriters. The relevant data they must employ is given in Table 1. Each appliance may be exchanged at any one of nine prices, represented by letters A through I. The buyer and seller each receive a profit sheet listing how much profit he / she will receive for each appliance at a given price. Neither the buyer nor the seller is given the other's corresponding profit data. (NOTE: For brevity, the buyer's profit sheet is illustrated by the left half of Table 1, and the seller's by the right half).

Table 1. Integrative bargaining task used by Pruitt and colleagues.

BUYER						SELLER					
Television Sets		Vacuum Cleaners		Typewriters		Television Sets		Vacuum Cleaners		Typewriters	
Price	Profit	Price	Profit	Price	Profit	Price	Profit	Price	Profit	Price	Profit
A	$2000	A	$1200	A	$800	A	$000	A	$000	A	$000
B	$1750	B	$1050	B	$700	B	$100	B	$150	B	$250
C	$1500	C	$900	C	$600	C	$200	C	$300	C	$500
D	$1250	D	$750	D	$500	D	$300	D	$450	D	$750
E	$1000	E	$600	E	$400	E	$400	E	$600	E	$1000
F	$750	F	$450	F	$300	F	$500	F	$750	F	$1250
G	$500	G	$300	G	$200	G	$600	G	$900	G	$1500
H	$250	H	$150	H	$100	H	$700	H	$1050	H	$1750
I	$000	I	$000	I	$000	I	$800	I	$1200	I	$2000

These profit sheets were structured to effect two important features. First, the buyer's and seller's prospective profits are inversely related with respect to each of the appliances. The buyer attains greatest profits at price A, while the seller obtains greatest profits at price I. Pruitt and his colleagues' investigations typically reveal that participants quickly realize this first feature, often proposing and agreeing to a simple compromise: a "horizontal" solution yielding a total profit (joint outcome) of $4000 (e.g., E-E-E, both buyer and seller earning $2000 each). This first feature makes the situation one of basic conflict, in which negotiators pursue their respective ends with exclusive reference to their respective profit listings.

The second feature is a similar inverse relationship between the relative importance of two of the appliances. The buyer may obtain his / her largest profit with television sets, whereas the seller may obtain his /her largest profit with typewriters. Vacuum cleaners are of moderate

importance to both the buyer and seller, and they have no effect on joint profit. To the extent the price of television sets is closer to A and the price of typewriters is closer to I, joint profit may exceed the $4000 obtained through simple compromise. A "diagonal" solution (e.g., A-E-I) yields the maximum joint profit of $5200 (each earning $2600). It takes open, honest communication and a flexible attitude toward possible options to recognize this second feature, which permits the development of mutually advantageous (integrative or win-win) tradeoffs. The extent of integration (mutual advantage) is operationalized in terms of joint outcome: the higher the joint profit, the more integrative the solution.

Based on research findings, Pruitt and Lewis (1977) identify and describe three strategies negotiators may utilize. First, a *distributive strategy* may be used. The distributive strategy refers to attempts to elicit concessions from the other bargainer through behaviors such as persuasion, threat, demands, or a dogmatic commitment to a particular offer. These types of behaviors have been found to be negatively correlated with joint profit. The distributive strategy's incompatibility with integrative bargaining is not because participants using this strategy are unwilling to make concessions, but because they do not approach the problem with the openness and flexibility required to obtain the integrative solution.

Information exchange is a second strategy bargainers may use. This involves asking for and giving truthful information regarding one another's profit structure (e.g., data from each other's profit sheets). Although measures of information exchange are positively (but not significantly) related to joint profit, the relationship is not strong. It seems that typically not enough information is exchanged for the average person to gain an insight of the profit structure. However, if very high levels of information exchange take place (e.g., if each bargainer is permitted to see the other's table), the integrative solution is usually found.

A final strategy employed by bargainers is called *heuristic trial and error*. This strategy is related to the way in which bargainers make proposals to one another. Indices of this strategy, which attempt to capture the openness and flexibility of bargainers' proposals as they discover integrative options, include the number of different proposals made, the degree to which proposals reflect the observed priorities of the other bargainer, and the alternation of proposals within a similar level of individual profit. Indices such as these are found to be strongly related to joint profit.

Pruitt and Lewis' (1977) go on to propose a theory of integrative bargaining based on their understanding of the research. Their theoretical framework depicts the two bargainers' behavior along two dimensions: *flexibility with respect to means* (the extent to which participants explore various available options) and *flexibility with respect to ends* (the extent to which each participant will reconsider his / her highest level of prospective profit). Flexibility of both means and ends tends to lead bargainers to premature agreement at a low level of profit. Although bargainers may be willing to try various proposals, they do not maintain a high goal and may therefore agree to a suboptimal solution before gaining insight into the profit structure. Rigidity of both means and ends results in the distributive tactics incompatible with integrative bargaining. While maintaining high goals, such bargainers do not explore various options but simply try to elicit concessions from one another. This leads either to failure to reach any agreement or (due to experimental demand to reach some agreement) to a simple compromise that is not mutually advantageous.

Rigidity of means and flexibility of ends leads to simple compromise at a low profit level. However, flexibility of means and rigidity of ends, *flexible rigidity*, leads to integrative solutions. Integrative bargaining occurs when each participant is willing to explore various options openly and maintains a high level of aspiration throughout the negotiation. That is, negotiators who flexibly try a variety of mechanisms (e.g., coordination, information exchange, logrolling) while rigidly maintaining rigorous and realistic goals are most likely to achieve objectively superior performance.

TRACE: Integrative Bargaining in an MDT Scenario

Members of a MDT share important similarities to negotiators in integrative bargaining. MDT members need to reach agreement, but have different perspectives (based on their respective expertise, backgrounds, and priorities). Better sharing and understanding of important information leads to a better outcome; it fosters better decision making, which in turn increases the design's effectiveness. If, rather than seeking simple compromise, the MDT members achieve a deeper understanding of the factors influencing design success, they can creatively implement advantageous tradeoffs that can save valuable resources and enhance performance.

Given the potential relevance of integrative bargaining research to MDTs, we decided to create our own integrative bargaining task, TRACE. Our goal was to maintain the basic structure and control of traditional integrative bargaining tasks while enriching TRACE with realistic details of the sort addressed in an actual design project. The context for TRACE is the design of an automobile navigation system, and the final form of the task is based on concrete information from actual designers. In conjunction with an associated effort to learn about collaboration in MDTs (Citera and Selvaraj, 1992; McNeese, Zaff, Brown, Citera, & Selvaraj, 1993), we had already collected a mass of data relevant to a hypothetical automobile navigation system project from personnel actively involved in design -- e.g., human factors specialists, engineers, an audio/video technician, and a software programmer. This was augmented by extended discussions with an evaluator for an actual automobile navigation system project. From this data we were able to develop TRACE as an elaborately structured task involving several elements. The data used by participants is illustrated in Table 2. Appendices A, B, & C give the subjects' experimental instructions and methodology, subject instruction, and contract agreement form, respectively).

Participants in TRACE play the role of either a Human Factors Expert (HFE) or a Program Manager (PM). The Human Factors Expert has knowledge of and concern for how attributes of the system will improve performance, and he / she wants to select various attractive (and expensive) attributes and options in order to enhance performance (maximize *PIUs, performance improvement units*). The Program Manager has knowledge of and concern for how attributes of the system will affect the cost of the system, and wants to select less expensive attributes and options in order to save money (maximize *dollars saved*).

Negotiations between the Human Factors Expert and Program Manager focus on system attributes within three categories: *Visual Display Hardware, Navigation Location Support, and Driver Input-Output Features*. For example, within the Visual Display Hardware category, eight configurations are possible based on three attributes: Display Resolution ("medium" vs. "high"), Display Size ("8 inch" vs. "10 inch"), and Number of Colors ("16" vs. "256"). Similarly, eight configurations are possible within the Navigation Location Support category based on Antennae Coverage ("moderate" vs. "high"), Error-Checking Capability ("normal" vs. "enhanced"), and Level of Database Detail ("standard" vs. "extended"). Likewise, eight configurations are possible within the Driver Input-Output Features category based on User Output Format ("text/graphic" vs. "plus voice"), User Input Format ("text input" vs. "plus menu") and Navigational Map Display ("track-up only" vs. "plus north-up").

Because in actual design some attributes are more important than others, attributes in TRACE differ in importance for both the Program Manager and the Human Factors Expert. For example, within the Visual Display Hardware category, Display Resolution is most important, Display Size is moderately important, and Number of Colors is least important (for both the Program Manager and the Human Factors Expert). Similarly, within the Navigation Location Support category, Antennae Coverage is most important, Error-Checking Capability is moderately important, and Level of Database Detail is least important. Within the Driver Input-Output Features category, User Output Format is most important, User Input Format is moderately important, and

Navigation Map Display is least important. In terms of our metrics (dollars saved and PIUs), within each category the most important attribute is worth twice as much as the moderately important attribute and four times as much as the least important attribute. For example, using a medium rather than a high resolution display saves $1000 (while sacrificing 400 PIUs), using an 8" rather than a 10 " display saves $500 (while sacrificing 200 PIUs), and using 16 colors rather than 256 colors saves $250 (while sacrificing 100 PIUs). The order of importance of the three attributes within each category is based upon our understanding of the domain derived from our discussions with subject matter experts about automobile navigation systems.

Within the TRACE task, advantageous tradeoffs are possible if relevant technical data (as presented in Table 2) are successfully integrated and applied to the problem. Specifically, the data provided indicate considerable savings can be realized without drastically sacrificing performance (in the area of Visual Display Hardware), and considerable performance enhancements can be realized without drastically sacrificing cost savings (in the area of Driver Input-Output Features). For example, selecting a medium rather than a high resolution display saves $1000 while reducing performance by only 400 PIUs. Conversely, under the category of Driver Input-Output Features selecting "text/graphic" rather than "plus voice" for the attribute of User Output Format saves only $400 while reducing performance by 1000 PIUs. More abstractly, the increased-savings-to-reduced-PIUs *ratio* is 2.5 to 1 for Visual Display Hardware, 1 to 1 for Navigation Location Support, and 1 to 2.5 for Driver Input-Output Features. Clearly, mutually advantageous tradeoffs can be achieved by simultaneously saving money in the category of Visual Display Hardware and increasing performance (PIUs) in the category of Driver Input-Output Features, where it is possible to get more "bang-for-the-buck." For the purposes of illustration, the Human Factors Expert and the Program Manager data have been integrated into a single table (see Table 2).

We need to point out several differences between the integrative bargaining tasks discussed earlier (Pruitt and colleagues') and TRACE (see Tables 1 and 2). First, because Pruitt and Lewis (1975) offered nine price categories (represented by letters A to I in Table 1) for each appliance, a simple compromise (letter E) was obvious and available. From our discussions with designers, such simple and obvious compromises are seldom available. The TRACE task's more complex arrangement of choices among eight design configurations within each of the three categories (Visual Display Hardware, Navigation Location Support, and Driver Input-Output Features) prevents participants from simply "meeting in the middle."

Second, TRACE better mirrors the type of design decisions common in practice. TRACE involves reasoning with values (dollars saved and PIUs) like those used by Pruitt and his colleagues (prices), and the differential importance attributed to options affords a comparability of metrics between the two tasks. Although TRACE's single dimension "configuration" is thus similar to Pruitt's single dimension "price," there is a key difference. Because each TRACE configuration represents a unique combination of three system attributes, subjects must decide to include or exclude specific system attributes or features. Such "include / exclude" choices are the same type of decisions that design professionals report as being the most common in practice.

Table 2. Combined data tables for Human Factors Expert and Program Manager.

Visual Display Hardware				PM	HF
Display Configuration	Display Resolution	Display Size	Display Colors	Dollars Saved	PIU Gained
1	Medium	8 inch	16 colors	$1750	0 piu
2	Medium	8 inch	256 colors	$1500	100 piu
3	Medium	10 inch	16 colors	$1250	200 piu
4	Medium	10 inch	256 colors	$1000	300 piu
5	High	8 inch	16 colors	$750	400 piu
6	High	8 inch	256 colors	$500	500 piu
7	High	10 inch	16 colors	$250	600 piu
8	High	10 inch	256 colors	$0	700 piu

Navigation Location Support				PM	HF
Navigation Configuration	Antennae Coverage	Error-checking Capability	Level of Database Detail	Dollars Saved	PIU Gained
1	Moderate	Normal	Standard	$1050	0 piu
2	Moderate	Normal	Extended	$900	150 piu
3	Moderate	Enhanced	Standard	$750	300 piu
4	Moderate	Enhanced	Extended	$600	450 piu
5	High	Normal	Standard	$450	600 piu
6	High	Normal	Extended	$300	750 piu
7	High	Enhanced	Standard	$150	900 piu
8	High	Enhanced	Extended	$0	1050 piu

Driver Input/Output Features				PM	HF
Input/Output Configuration	User Output Format	User Input Format	Navigational Map Display	Dollars Saved	PIU Gained
1	Text/Graphic	Text Input	Track-Up Only	$700	0 piu
2	Text/Graphic	Text Input	Plus North-Up	$600	250 piu
3	Text/Graphic	Plus Menu	Track-Up Only	$500	500 piu
4	Text/Graphic	Plus Menu	Plus North-Up	$400	750 piu
5	Plus Voice	Text Input	Track-Up Only	$300	1000 piu
6	Plus Voice	Text Input	Plus North-Up	$200	1250 piu
7	Plus Voice	Plus Menu	Track-Up Only	$100	1500 piu
8	Plus Voice	Plus Menu	Plus North-Up	$0	1750 piu

Third, in Pruitt's paradigm the bases for mutually advantageous tradeoffs (televisions are most important for the buyer, whereas typewriters are most important for the seller) are simply arbitrary structural features of the task. Like Pruitt's task, at the metric unit level, TRACE includes opportunities for each participant to gain 250 units (dollars or PIUs) while the other participant sacrifices 100 units (recall the 2.5 to 1 ratio), for a 150 unit tradeoff advantage. However, the bases for mutually advantageous tradeoffs in our automobile navigation system task are not arbitrary; they are based on lessons learned from design experience. That is, it is a common human factors principle that performance enhancements can often be achieved at relatively little cost through thoughtful design of the interface (Norman and Draper, 1986). This is instantiated in TRACE by our Driver Input-Output Features category being of greatest importance for enhancing performance and least important for leveraging cost savings. On the other hand, in design there is frequently a "point of diminishing returns" beyond which very expensive hardware offers little added performance over more moderately priced alternatives (Papanek, 1973). This is instantiated in TRACE by our Visual Display Hardware category being of greatest importance for leveraging savings and of least importance for enhancing performance. The Navigation Location Support category (like Pruitt's vacuum cleaners) is of moderate importance to both goals and is neutral with respect to joint outcomes.

Finally, we believe our TRACE automobile navigation system design task surpasses earlier integrative bargaining tasks by providing a richer context for discussion and negotiation. Where Pruitt's buyer and seller simply decide on three prices affecting each's overall profit, TRACE 's Program Manager and Human Factors Expert must decide on specific permutations of nine system attributes in terms of improving economy (maximizing dollars saved) or improving performance (maximizing PIUs). This creates a more complex negotiation where the participants have different foci and metrics for success. In the TRACE context, the discovery of mutually advantageous tradeoffs is more realistic and challenging. Furthermore, our participants discuss attributes and options relevant to an actual design problem in an area where they all have personal experience (as drivers and/or passengers). This allows participants to engage in discussions about the attributes and their implications at an intuitive level, regardless of the data provided about the attributes' "true value" (dollars saved and PIUs). This reflects the problem faced in actual multidisciplinary design deliberations in which data may be ignored or underutilized with potentially adverse consequences.

Validating TRACE is a research issue that can only be incrementally tested rather than conclusively proven. The following section provides a description of our first "pass" at assessing the ecological validity of the TRACE task. We hypothesized that if the paradigm reasonably captures the context of real-world multidisciplinary design practice, individuals with actual design experience will perform better than individuals with little or no design experience.

METHOD

Subjects

A total of 44 subjects were recruited to form two comparison groups of 22 each. Our "Novices" were undergraduate students from a small midwestern university, and our "Experts" were working professionals from the Aeronautical Systems Center and Human Engineering Division of Armstrong Laboratory at Wright-Patterson Air Force Base. Within each comparison group, eleven Program Manager-Human Factors Expert dyads were formed. In the case of the "Novices," subjects were randomly assigned to role-play either a Program Manager or a Human Factors Expert. In the case of the "Experts," role assignment was based on the subject's prior experience. Of the 22 "Expert" subjects, eleven had program managerial experience (mean = 12.6 years) and eleven had human factors engineering/psychology experience (mean = 7.6 years).

Apparatus and Setup

The experimental setting was a conference room in which subjects were seated facing each other across a conference table. The data tables (Appendix B) were positioned in the center of the conference table, upright and back-to-back, so that each subject could see only the data table appropriate to his/her role. Each dyad was given a "Design Contract Agreement" form for recording its decision, pencils, and sheets of paper. A video camera was aimed over each subject's shoulder to videotape the subject opposite (upper body only) (See Figure 1). A special effects generator combined the two views into one picture such that when one subject was looking at the other he/she was looking toward the center screen. Although participants were aware that they were being videotaped, the cameras were obscured (partially hidden) to make them relatively unobtrusive in order to reduce evaluation apprehension.

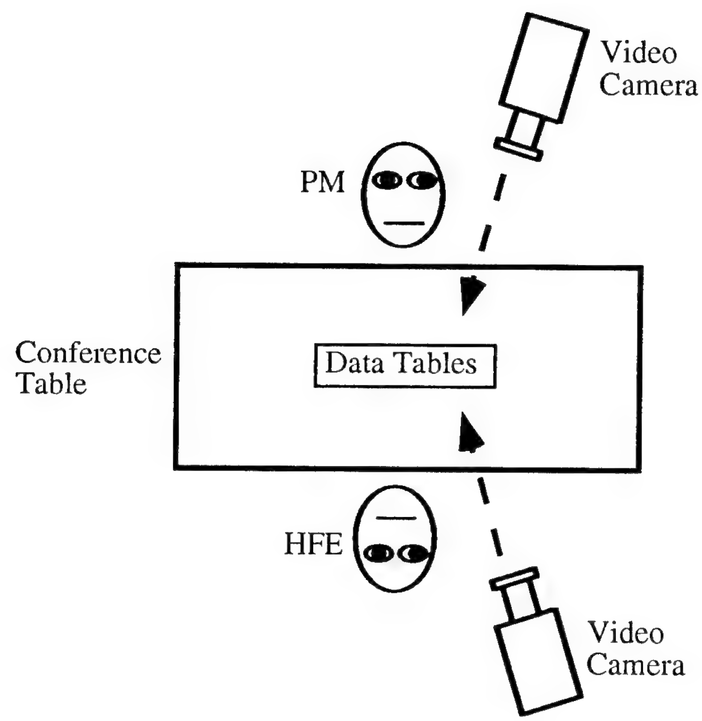

Figure 1. Illustration of experimental setup including placement of cameras, subjects and data tables. Subjects are seated facing one another.

Experimental Design

The independent variable was the level of design experience (i.e., Novice vs. Expert). The dependent measure was the combined total of the PIUs gained and the dollars saved by the team, which could range in value from 2450 to 4550 in 150 unit increments. Termed "joint outcome," this dependent measure was used as an index of the quality (i.e., level of integration) of agreement between team members. The higher the joint outcome the more integrative the agreement reached by group members; the lower the joint outcome, the less integrative the agreement. Design teams

failing to reach any agreement were to be assigned a joint outcome one increment (150 units) below the lowest joint outcome value eventually obtained in our data set.

Procedure

Subjects were separately given instructions and task descriptions specific to their respective roles (i.e., Program Manager or Human Factors Expert). The instructions were intended to establish a problem solving orientation with a high level (at least $2000 saved and $2000 PIUs) of aspiration requiring mutually advantageous tradeoffs for success (Pruitt and Lewis, 1975). Subjects were told they could verbally share any information concerning their data with the other team member, but they could not show him/her their data tables. Subjects were then brought into the conference room and instructed that they would have 15 minutes to complete the task. They were told that if at the end of 15 minutes they had not reached agreement, they would be given an additional five minutes to do so. They were told that if they did not reach an agreement at the conclusion of the additional five minutes, the project would fail. Once the subjects reached agreement, or the 20 minutes elapsed, the bargaining session was concluded.

RESULTS

Statistical Analyses

In our study, actual joint outcome values ranged from a low of 3050 to a "perfect" 4550. Teams failing to reach agreement were assigned joint outcome scores of 2900 (150 units below the minimum score obtained with agreement). It was hypothesized that if the paradigm reasonably captures the context of real-world multidisciplinary design practice, then Experts should perform better than Novices. To test this hypothesis, an independent t-test was conducted using joint outcome as the dependent variable. The independent variable was level of experience (i.e., Novice vs. Expert). Expert dyads had significantly higher joint outcomes ($\underline{M} = 4100$) than did Novices ($\underline{M} = 3500$), $\underline{t}(20) = 2.33$, $p<.05$. Three Expert dyads obtained "perfect" joint outcomes of 4550, and two Expert dyads failed to reach any agreement. The highest joint outcome by Novices was 4250 (achieved by one dyad), and four Novice dyads failed to reach any agreement. These results support our original hypothesis.

Process Analysis

In order to the understand nature of tradeoff negotiations, we needed to discern those factors within the dyads' negotiations salient to a successful level of integration. A process analysis was conducted via a review of the videotapes from the experimental sessions. An analyst used a structured checklist to track the occurrence of any of four specific acts -- (1) one negotiator's quoting information revealed by the other; (2) one negotiator's stating an attribute was necessary; (3) the presentation of a complete proposal (complete configuration covering all 3 categories); and (4) the tallying of outcomes for any proposed or intermediate solutions (exclusive of the final solution). Tables 3, 4, and 5 present the process categories and checklists used to evaluate each dyad. Table 6 presents the results of this procedure.

Table 3. Process categories used in evaluating dyad interaction.

GENERAL CHECKLIST POINTS:

•Did the PROGRAM MANAGER quote information revealed by the HF EXPERT?

GOAL

TABLE INFO

CATEGORY PRIORITIES

•Did the HF EXPERT quote information revealed by the PROGRAM MANAGER?

GOAL

TABLE INFO

CATEGORY PRIORITIES

•Did one or the other state specific attributes (e.g. Error-Checking) as necessary (implied rigidness) to include or exclude?

PROGRAM MANAGER?

HF EXPERT?

•How many distinct *complete* proposals (i.e. a configuration covering all 3 categories) were put "on the table"?

PROGRAM MANAGER?

HF EXPERT?

•How many times did they tally the outcome of proposed/intermediate solutions (not counting final solutions)?

PROGRAM MANAGER?

HF EXPERT?

Table 4. Checklist for evaluating level of Program Manager information exchanged.

Program Manager

Goal = $2000

Most (self) least (other)		Visual Display Hardware		Increment = $250
Display Configuration	**Display Resolution**	**Display Size**	**Display Colors**	**Dollars Saved**
1	Medium	8 inch	16 colors	$1750 MAX
2	Medium	8 inch	256 colors	$1500
3	Medium	10 inch	16 colors	$1250
4	Medium	10 inch	256 colors	$1000
5	High	8 inch	16 colors	$750
6	High $1000	8 inch	256 colors	$500
7	High	10 inch $500	16 colors $250	$250
8	High	10 inch	256 colors	$0 MIN
	most (s) most (o)		least (s) least (o)	

		Navigation Location Support		Increment = $150
Navigation Configuration	**Antennae Coverage**	**Error-checking Capability**	**Level of Database Detail**	**Dollars Saved**
1	Moderate	Normal	Standard	$1050 MAX
2	Moderate	Normal	Extended	$900
3	Moderate	Enhanced	Standard	$750
4	Moderate	Enhanced	Extended	$600
5	High	Normal	Standard	$450
6	High $600	Normal	Extended	$300
7	High	Enhanced $300	Standard $150	$150
8	High	Enhanced	Extended	$0 MIN
	most (s) most (o)		least (s) least (o)	

Least (self) most (other)		Driver Input/Output Features		Increment = $100
Input/Output Configuration	**User Output Format**	**User Input Format**	**Navigational Map Display**	**Dollars Saved**
1	Text/Graphic	Text Input	Track-Up Only	$700 MAX
2	Text/Graphic	Text Input	Plus North-Up	$600
3	Text/Graphic	Plus Menu	Track-Up Only	$500
4	Text/Graphic	Plus Menu	Plus North-Up	$400
5	Plus Voice	Text Input	Track-Up Only	$300
6	Plus Voice $400	Text Input	Plus North-Up	$200
7	Plus Voice	Plus Menu $200	Track-Up Only $100	$100
8	Plus Voice	Plus Menu	Plus North-Up	$0 MIN
	most (s) most (o)		least (s) least (o)	

Table 5. Checklist for evaluating level of Human Factors information exchange.

Human Factors Expert

Goal = 2000 pius

Least (self) most (other) — **Visual Display Hardware** — **Increment = 100 pius**

Display Configuration	Display Resolution	Display Size	Display Colors	Performance Units Gained
1	Medium	8 inch	16 colors	0 piu **MIN**
2	Medium	8 inch 200piu	256 colors 100piu	100 piu
3	Medium 400piu	10 inch	16 colors	200 piu
4	Medium	10 inch	256 colors	300 piu
5	High	8 inch	16 colors	400 piu
6	High	8 inch	256 colors	500 piu
7	High	10 inch	16 colors	600 piu
8	High	10 inch	256 colors	700 piu **MAX**
	most (s) most (o)		least (s) least (o)	

Navigation Location Support — **Increment = 150 pius**

Navigation Configuration	Antennae Coverage	Error-checking Capability	Level of Database Detail	Performance Units Gained
1	Moderate	Normal	Standard	0 piu **MIN**
2	Moderate	Normal 300piu	Extended 150piu	150 piu
3	Moderate 600piu	Enhanced	Standard	300 piu
4	Moderate	Enhanced	Extended	450 piu
5	High	Normal	Standard	600 piu
6	High	Normal	Extended	750 piu
7	High	Enhanced	Standard	900 piu
8	High	Enhanced	Extended	1050 piu **MAX**
	most (s) most (o)		least (s) least (o)	

Most (self) least (other) — **Driver Input/Output Features** — **Increment = 250 pius**

Input/Output Configuration	User Output Format	User Input Format	Navigational Map Display	Performance Units Gained
1	Text/Graphic	Text Input	Track-Up Only	0 piu **MAX**
2	Text/Graphic	Text Input 500piu	Plus North-Up 250piu	250 piu
3	Text/Graphic 1000piu	Plus Menu	Track-Up Only	500 piu
4	Text/Graphic	Plus Menu	Plus North-Up	750 piu
5	Plus Voice	Text Input	Track-Up Only	1000 piu
6	Plus Voice	Text Input	Plus North-Up	1250 piu
7	Plus Voice	Plus Menu	Track-Up Only	1500 piu
8	Plus Voice	Plus Menu	Plus North-Up	1750 piu **MIN**
	most (s) most (o)		least (s) least (o)	

Table 6. Process analysis results.

	Expert Dyads			Novice Dyads		
	S	U	Total	S	U	Total
N	8	3	11	4	7	11
Attribute Necessary	4	2	6	2	4	6
Proposals Made	20	1	21	11	14	25
Proposals Tallied	45	3	48	13	44	57
Total Shared Information	192	2	194	10	74	84

Note. "S" denotes a successful level of integration (i.e., both participants reached at least 2000) and "U" denotes an unsuccessful level of integration.

As indicated in Table 6, successful Experts (as opposed to unsuccessful ones) made more proposals, tallied more proposals, shared more information, and more frequently stated an attribute as being necessary. Successful Novices (as opposed to unsuccessful Novices) made fewer proposals, tallied fewer proposals, shared less information, and less frequently stated an attribute as being necessary. Overall, Novices made more proposals, tallied more proposals, and shared less information than Experts. Both Experts and Novices seemed to use distributive strategies in negotiating and making proposals. This was indicated by a stable and equivalent proportion (i.e., 6 overall) of Expert and Novice dyads that perceived an attribute as necessary. Roughly two proposals in each Expert and Novice dyad could be categorized as being the product of a heuristic trial-and-error strategy. However, variation among the dyads was high with respect to this strategy. Finally, these data suggest that information exchange was associated with successful performance for Experts and poor performance for Novices.

DISCUSSION

Experts were more successful than Novices in reaching and discovering mutually advantageous tradeoffs in the TRACE design task. While these results support our validation effort, they are not sufficient to close the issue. A more conclusive assessment would require evidence of a more exclusive linkage between our Experts' performance and their design experience (as opposed to, e.g., age or education). As such, we believe it most accurate at this stage to characterize our results as positive but not conclusive.

In addition to assessing the quality of the integrative decision we also assessed whether our experimental focus (tradeoffs) in TRACE reflected real-world design practices. We followed the Experts' bargaining sessions by administering a questionnaire on: 1) the importance of cost/performance tradeoffs, 2) the difficulty of discovering mutually advantageous low-cost/high-performance tradeoffs, and 3) the importance of discovering mutually advantageous low-cost/high-performance tradeoffs in actual design projects. Experts rated each of the three items on a five point Likert type scale (i.e., 1 = not at all, 5 = very). Responses indicated they perceive

cost/performance tradeoffs as very important in the design process, and that it is very important and very difficult to discover mutually advantageous tradeoffs (see Table 7).

Table 7. Mean Ratings on Experts' Perceptions of Tradeoffs.

	Mean
Importance of Tradeoffs	4.73
Difficulty of Discovery	4.32
Importance of Discovery	4.60

Means were based on a five-point Likert type scale (i.e., 1 = not at all, 5 = very).

From our protocol analyses, we found that Expert dyads exchanged more information than Novice dyads. Relatively high levels of information exchange helped Experts discover advantageous tradeoffs, but proved to be detrimental to the performance of the Novice dyads. Pruitt and Lewis (1975) suggest an information-exchange approach aids bargainers who have high cognitive complexity. To the extent that our Experts have high cognitive complexity with regard to our task context, these data tend to support this assertion. When Novices exchanged high levels of information, they had lower joint outcomes. Perhaps the students found the information in the automobile navigation context too complicated to understand well enough to successfully arrive at mutually advantageous decisions. For example, in one case students seemed to be completely frustrated by the task complexity and just gave up.

Based on the combination of the joint outcome analysis, the Experts' questionnaire, and preliminary protocol analyses, we find no basis for rejecting or significantly modifying the TRACE task as formulated to date. The predictions of integrative bargaining theory are borne out by our initial experiments, as is our hypothesis regarding the relative performance of Experts versus Novices. We therefore believe the TRACE experimental paradigm passed its first validation test.

TRACE's Future as a Research Tool and Validation Testbed

We have continued our work by outlining TRACE's promise as an instrument for exploring tradeoff negotiation in collaborative design. We will conclude by noting some ways in which the TRACE work could be carried forward to integrate research into design tradeoff negotiation and to validate the applied results of such research.

We suggest that TRACE can be used as a testbed for integrating and extending earlier research work on information sharing and its impact on design decision making. Stasser and his colleagues (Stasser and Stewart, 1992; Stasser and Titus, 1985) have found *biased information sampling* in face-to-face decision making groups. This is evidenced by shared information (previously known by two or more individuals) being discussed at length and weighing heavily in eventual decisions and unshared information (previously known by only one person) being omitted or only briefly mentioned and then ignored, resulting in suboptimal decisions. The work of Stasser and his colleagues is interesting, but their employment of relatively simplistic task scenarios limits its applicability.

TRACE would lend itself to extending this sort of information sharing research. TRACE's shared information consists of the attributes under consideration and the basic understanding of an inverse relationship between performance enhancement and cost savings. TRACE's unshared

information consists of the specific degree of performance enhancement and cost savings associated with the attributes. Because it is this unshared information which is critical to the discovery of mutually advantageous tradeoffs in TRACE, enhanced consideration of unshared information should correlate with enhanced integration of outcomes. We suggest it would be very profitable to revisit Stasser's work using the more complex TRACE paradigm.

TRACE was initially developed to serve as an experimental testbed for researching MDT interaction and performance to generate knowledge of MDT human factors characteristics. We hope that such knowledge will lead to the prescription of constructive innovations to improve MDT performance. Our overriding concern for TRACE's ecological validity was motivated by the need for confidence in generalizing upon TRACE's results. When this confidence is fully justified (if not already), we suggest it would facilitate TRACE's utility in the reverse direction -- i.e., validating the application of human factors knowledge to the construction and deployment of novel MDT support tools. Examples of specific issues and factors which could be examined using TRACE include: collaboration tools; group process management procedures; information format and accessibility; data visualization techniques; information sharing and decision making in groups; and group organization and structure.

REFERENCES

Boff, K. R. (1987). The tower of Babel revisited: On cross-disciplinary chokepoints in system design. In W. B. Rouse and K. R. Boff (Eds.), *System design: Behavioral perspectives on designers, tools, and organizations* (pp. 83-96). New York: Elsevier.

Boff, K. R., Monk, D. L., Swierenga, S. J., Brown, C. E., & Cody, W. J. (1991). Computer-aided human factors for system designers. *Proceedings of the Human Factors Society 35th Annual Meeting, 1*, 332-336.

Brunswik, E. (1956). *Perception and the representative design of psychological experiments.* Berkeley: University of California Press.

Bucciarelli, L. L. (1988). An ethnographic perspective on engineering design. *Design Studies, 9*, 159-168.

Citera, M., and Selvaraj, J. A. (1992). *Development of a research paradigm to study collaboration in multidisciplinary design teams.* Washington DC: Air Force Office of Scientific Research.

Cody, W. J., Rouse, W. B., and Boff, K. R. (1993). *Automated information management for designers: Functional requirements for computer based associates that support and use of technical information in design.* AL-TR-1993-0069. Wright-Patterson Air Force Base, OH: Armstrong Laboratory (DTIC No. A274603).

McNeese, M. D., Zaff, B. S., Brown, C. E, Citera, M., and Selvaraj, J. A. (1993). Understanding the context of multidisciplinary design: A case for establishing ecological validity in the study of design problem solving. *Proceedings of the 37th Annual Meeting of the Human Factors Society, 2*, 1082-1086.

Norman, D., and Draper, S. (Eds.) (1986). *User centered system design.* Hillsdale NJ: Lawrence Erlbaum Associates.

Papanek, V. (1973). *Design for the real world.* New York: Bantam.

Pruitt, D. G. (1981). *Negotiation behavior.* New York: Academic Press.

Pruitt, D. G., and Carnevale, P. J. (1993). *Negotiation in social conflict.* Pacific Grove, CA: Brooks/Cole.

Pruitt, D. G., and Lewis, S. A. (1975). Development of integrative solutions in bilateral negotiation. *Journal of Personality and Social Psychology, 31*, 621-633.

Pruitt, D. G., and Lewis, S. A. (1977). The psychology of integrative bargaining. In D. Druckman (Ed.), *Negotiations: A social psychological perspective.* Beverly Hills: Sage-Halsted.

Stasser, G., & Titus, W. (1985). Pooling of unshared information in group decision making: Biased information sampling during group discussion. *Journal of Personality and Social Psychology, 48*, 1467-1478.

Stasser, G., & Stewart, D. (1992). Discovery of hidden profiles by decision-making groups: Solving a problem versus making a judgement. *Journal of Personality and Social Psychology, 63*, 426-434.

Appendix A

TRACE Task Instructions and Methodology

TRACE INSTRUCTIONS

EXPERIMENTER

-Experimenter greets the subjects and says:

> "Today you are going to participate in a role playing experiment. A random drawing will be used to assign you each to different roles [For Novices] [draw cards] [For Experts][Based on your experience, you will be assigned different roles.] <u>(Name of HFE)</u>, you will be assigned the role of Human Factors Expert and <u>(Name of Program Manager)</u>, you will be assigned the role of Program Manager. You will read your instructions, based on your role, individually and then be brought back together to perform the experiment. You will now be taken to different rooms where you will read both the consent form and your instructions."

-Instructors escort their subject to designated areas.

INSTRUCTORS

<u>Consent Form and Task Instructions</u>

-Give the subject their instructions and say:

> "Here is your consent form. Please read along as I read the form to you."

-Read the consent form and answer questions the subject may have. Have them sign the form.
-Give the subject their instructions and say:

> "Now that you have signed the consent form, I will give you the conditions in which you will be role playing. Here are your instructions. Read them silently as I read them aloud. Feel free to stop me at any time and ask questions."

-Answer questions the subject has.

<u>Strategy Instructions</u>

-Have the subject go to the last page of their instructions:

> "Now that you have read and understand the instructions for this task, here are the goals and strategies that you should keep in mind while working on this task. Please read along as I read to you. Stop me if you have any questions."

-Answer questions the subject might have and then escort the subject back to the experimental room.

<u>Experimental Room Instructions</u>

-While the experimenter is giving the final instructions to the subjects, make final adjustments to the cameras. Adjust for height and make adjustments to the audio levels.

-Just before the experimenter leaves the room, start the VCR (i.e., press 'play' and 'record' buttons simultanously.

EXPERIMENTER

-Experimenter seats the subjects in their places and says:

> "You are allowed to say anything to the other participant but do not move the tables in front of you or show them to the other participant. Try to complete the role playing experiment in 15 minutes. That is, you need to be able to complete the Automobile Navigation System Design Contract (i.e., write down the number, configuration, and attributes you chose in the Visual Display Hardware, Navigation Location Support, and Driver Input-Output Features sections) in the 15 minutes allotted. If at the end of 15 minutes you have not completed the contract (i.e., made your configuration choices and initialed the contract), you will be given an additional 5 minutes to do so. If you have not initialed the contract by the end of those final 5 minutes, the project will fail.
>
> After you have completed this phase of the experiment, we will take you to separate rooms to fill out a short post experimental questionnaire. You may begin the experiment as soon as I leave the room and once again thank you for participatiing in this study."

-Experimenter leaves the room.

Appendix B

TRACE Instructions for Program Manager and Human Factors Expert

Automobile Navigation System Project for Program Manager

In this study you will be playing the role of a program manger and the other participant will be playing the role a human factors expert. You will both be working on the development of an automobile navigation system. The program manager is responsible for the project's budget and is therefore concerned with saving money on the project. The human factors expert is responsible for assuring that the driver of the automobile will be able to use the system effectively and is therefore concerned with improving the performance of the system.

The automobile navigation system is a computer based system that is intended to help drivers find their destination quickly and efficiently. This system will be able to track the location of the automobile and give the driver helpful information such as the time and distance to reach the destination, the best route to take, and specific directions, such as turn left at the next traffic light.

Three areas of the system which you and the other participant will discuss are the **Visual Display Hardware**, which will display text and graphic information on a computer monitor within the car; **Navigation Location Support**, which uses signals transmitted from a satellite to constantly monitor the car's location; and **Driver Input-Output** which concerns how the driver will tell the system the intended destination and how the system will tell the driver appropriate directions and instructions.

Before any additional progress can be made on the project, specific decisions need to be made with regard to these three areas of the system. In order to help you with your decisions you have been provided a table which summarizes important information you will need during your discussions. You will have a copy of the table with you during your interaction. Because you, the program manager, are most concerned with saving money your table shows the amount of money that could be saved by selecting particular configurations. Because the other participant, as the human factors expert is most concerned with performance, his or her table shows the performance improvement units (piu's) that could be gained by selecting particular configurations. You, as program manager, will not be able to see the performance improvement units (piu's) associated with the various configurations, and the other participant, as human factors expert will not be able to see the dollars saved with the various configurations.

At this point in the design process a basic system, **Configuration 1**, and an elaborate system, **Configuration 8**, have been developed for each of the three areas: **Visual Display Hardware**, **Navigation Location Support**, and **Driver Input-Output**. The basic system configuration saves the most money but performs least effectively; whereas the elaborate system configuration saves the least money but performs most effectively. Because you as the Program Manager are most concerned with saving money, you favor the basic system configuration. Because the Human Factors Expert is most concerned with improving performance, he/she favors the elaborate system. The basic and elaborate system configurations are made up of various design features. Because these features can be selected independently, a range of **Configurations, 1** through **8**, exists. Any of these system configurations, which vary in money saved and performance improvement units gained, may be selected within each of the three areas: **Visual Display Hardware**, **Navigation Location Support**, and **Driver Input-Output**.

Visual Display Hardware

The Visual Display Hardware will display text and graphic information on a computer monitor within the car. With regard to the **Visual Display Hardware**, decisions for three features must be made. The first feature, **display resolution**, the clarity and precision of the display, can be either a medium resolution screen or high resolution screen. The second feature, **display size**, the size of the display monitor, can be either an 8 inch monitor or a 10 inch monitor. The third feature, **display colors**, is the number of possible colors, and can be either 16 colors or 256 colors.

The basic system, **Configuration 1**, uses a medium resolution screen, an 8 inch monitor, and has 16 colors; whereas the elaborate system, **Configuration 8**, uses a high resolution screen, a 10 inch monitor, and has 256 colors. Because the decision for each of these three Visual Display Hardware features can be made independently, eight different Visual Display Hardware configurations are possible. Each of these eight configurations varies in price and performance, from the basic system which saves the most money but performs least effectively all the way to the elaborate system, which saves the least money but performs most effectively. Any one of these eight Visual Display Hardware configurations may be selected.

Navigation Location Support

The Navigation Location Support uses signals transmitted from a satellite to constantly monitor the car's location. With regard to **Navigation Location Support**, decisions for three features must be made. The first feature, **antennae coverage**, represents the level of accuracy used to locate the current position of the automobile. The antennae coverage can be either of moderate accuracy (within 30 meters) or of high accuracy (within 10 meters). The second feature, **error-checking capability**, is the error checking capability of the the vehicle's navigation system which attempts to correct for problems such as signal drift, and signal blockages due to tall buildings, tunnels, parking garages, etc. The error-checking capability includes either normal error-checking capability or an enhanced error-checking capability. The third feature, **level of database detail**, can either be the standard database (including only major streets and landmarks) or the extended database (including both major and minor streets and landmarks).

The basic system, **Configuration 1**, uses the moderate accuracy antennae, normal error checking, and the standard database; whereas the elaborate system, **Configuration 8**, uses the high accuracy antennae, enhanced error checking, and the extended database. Because the decision for each of these three Navigation Location Support features can be made independently, eight different Navigation Location Support configurations are possible. Each of these eight configurations varies in price and performance, from the basic system which saves the most money but performs least effectively all the way to the elaborate system, which saves the least money but performs most effectively. Any one of these eight Navigation Location Support configurations may be selected.

Driver Input-Output Features

The Driver Input-Output concerns how the driver will tell the system the intended destination and how the system will tell the driver appropriate directions and instructions. With regard to **Driver Input-Output Features**, decisions for three features must be made. The first feature, **driver output format**, can be text/graphics output, or text and graphics plus voice output. The second feature, **driver input format**, involves either the driver entering text input information or having the option of entering text information plus menu selection. The third feature, **navigational map display**, can be track-up only (where the map display changes orientation so that the car symbol is

always heading toward the top of the screen), or track-up, plus north-up map display option (where the option exists to have the map display oriented with north at the top of the screen, regardless of the cars direction of travel).

The basic system, **Configuration 1**, uses text/graphics output, text input only, and the track-up only map display; whereas the elaborate system, **Configuration 8**, uses text and graphics plus voice output, text plus menu display input, and the track-up plus north-up map display option. Because the decision for each of these three Driver Input-Output Features can be made independently, eight different Driver Input-Output configurations are possible. Each of these eight configurations varies in price and performance, from the basic system which saves the most money but performs least effectively all the way to the elaborate system, which saves the least money but performs most effectively. Any one of these eight Driver Input-Output configurations may be selected.

Program Manager

As the Program Manager, you should use the following decision making strategy in your interactions with the Human Factors Expert:

View the situation as a design problem in which your job is to attempt to play down the conflict nature of the task and view it as a problem to be solved. Naturally, you want to save as much money as you can, but you are also interested in improving the performance of the system and thereby meeting the needs of the Human Factors Expert.

Due to budgetary constraints it is crucial that $2000 are saved from the development costs of the Automobile Navigation System project. Any additional savings that can be gained would prove beneficial to both you and to the consumers of the product that you are developing.

Visual Display Hardware

Display Configuration	Display Resolution	Display Size	Display Colors	Dollars Saved
1	Medium	8 inch	16 colors	$1750
2	Medium	8 inch	256 colors	$1500
3	Medium	10 inch	16 colors	$1250
4	Medium	10 inch	256 colors	$1000
5	High	8 inch	16 colors	$750
6	High	8 inch	256 colors	$500
7	High	10 inch	16 colors	$250
8	High	10 inch	256 colors	$0

Navigation Location Support

Navigation Configuration	Antennae Coverage	Error-checking Capability	Level of Database Detail	Dollars Saved
1	Moderate	Normal	Standard	$1050
2	Moderate	Normal	Extended	$900
3	Moderate	Enhanced	Standard	$750
4	Moderate	Enhanced	Extended	$600
5	High	Normal	Standard	$450
6	High	Normal	Extended	$300
7	High	Enhanced	Standard	$150
8	High	Enhanced	Extended	$0

Driver Input/Output Features

Input/Output Configuration	User Output Format	User Input Format	Navigational Map Display	Dollars Saved
1	Text/Graphic	Text Input	Track-Up Only	$700
2	Text/Graphic	Text Input	Plus North-Up	$600
3	Text/Graphic	Plus Menu	Track-Up Only	$500
4	Text/Graphic	Plus Menu	Plus North-Up	$400
5	Plus Voice	Text Input	Track-Up Only	$300
6	Plus Voice	Text Input	Plus North-Up	$200
7	Plus Voice	Plus Menu	Track-Up Only	$100
8	Plus Voice	Plus Menu	Plus North-Up	$0

Automobile Navigation System Project for Human Factors Expert

In this study you will be playing the role of a human factors expert and the other participant will be playing the role of a program manager. You will both be working on the development of an automobile navigation system. The human factors expert is responsible for assuring that the driver of the automobile will be able to use the system effectively and is therefore concerned with improving the performance of the system. The program manager is responsible for the project's budget and is therefore concerned with saving money on the project.

The automobile navigation system is a computer based system that is intended to help drivers find their destination quickly and efficiently. This system will be able to track the location of the automobile and give the driver helpful information such as the time and distance to reach the destination, the best route to take, and specific directions, such as turn left at the next traffic light.

Three areas of the system which you and the other participant will discuss are the **Visual Display Hardware**, which will display text and graphic information on a computer monitor within the car; **Navigation Location Support**, which uses signals transmitted from a satellite to constantly monitor the car's location; and **Driver Input-Output** which concerns how the driver will tell the system the intended destination and how the system will tell the driver appropriate directions and instructions.

Before any additional progress can be made on the project, specific decisions need to be made with regard to these three areas of the system. In order to help you with your decisions you have been provided a table which summarizes important information you will need during your discussions. You will have a copy of the table with you during your interaction. Because you, as the human factors expert are most concerned with performance, your table shows the performance improvement units (piu's) that could be gained by selecting particular configurations. Because the other participant, as the program manager, is most concerned with saving money his or her table shows the amount of money that could be saved by selecting particular configurations. You, as the human factors expert will not be able to see the dollars saved with the various configurations, and the other participant, as program manager, will not be able to see the performance improvement units (piu's) associated with the various configurations.

At this point in the design process a basic system, **Configuration 1**, and an elaborate system, **Configuration 8**, have been developed for each of the three areas: **Visual Display Hardware**, **Navigation Location Support**, and **Driver Input-Output**. The basic system configuration saves the most money but performs least effectively; whereas the elaborate system configuration saves the least money but performs most effectively. Because you as the Human Factors Expert are most concerned with improving performance, you favor the elaborate system. Because the Program Manager is most concerned with saving money, he or she favors the basic system configuration. The basic and elaborate system configurations are made up of various design features. Because these features can be selected independently, a range of **Configurations, 1** through **8**, exists. Any of these system configurations, which vary in money saved and performance improvement units gained, may be selected within each of the three areas: **Visual Display Hardware**, **Navigation Location Support**, and **Driver Input-Output**.

Visual Display Hardware

The Visual Display Hardware will display text and graphic information on a computer monitor within the car. With regard to the **Visual Display Hardware**, decisions for three features must be made. The first feature, **display resolution**, the clarity and precision of the display, can be either a medium resolution screen or high resolution screen. The second feature, **display size**, the size of the display monitor, can be either an 8 inch monitor or a 10 inch monitor. The third feature, **display colors**, is the number of possible colors, and can be either 16 colors or 256 colors.

The basic system, **Configuration 1**, uses a medium resolution screen, an 8 inch monitor, and has 16 colors; whereas the elaborate system, **Configuration 8**, uses a high resolution screen, a 10 inch monitor, and has 256 colors. Because the decision for each of these three Visual Display Hardware features can be made independently, eight different Visual Display Hardware configurations are possible. Each of these eight configurations varies in price and performance, from the basic system which saves the most money but performs least effectively all the way to the elaborate system, which saves the least money but performs most effectively. Any one of these eight Visual Display Hardware configurations may be selected.

Navigation Location Support

The Navigation Location Support uses signals transmitted from a satellite to constantly monitor the car's location. With regard to **Navigation Location Support**, decisions for three features must be made. The first feature, **antennae coverage**, represents the level of accuracy used to locate the current position of the automobile. The antennae coverage can be either of moderate accuracy (within 30 meters) or of high accuracy (within 10 meters). The second feature, **error-checking capability**, is the error checking capability of the the vehicle's navigation system which attempts to correct for problems such as signal drift, and signal blockages due to tall buildings, tunnels, parking garages, etc. The error-checking capability includes either normal error-checking capability or an enhanced error-checking capability. The third feature, **level of database detail**, can either be the standard database (including only major streets and landmarks) or the extended database (including both major and minor streets and landmarks).

The basic system, **Configuration 1**, uses the moderate accuracy antennae, normal error checking, and the standard database; whereas the elaborate system, **Configuration 8**, uses the high accuracy antennae, enhanced error checking, and the extended database. Because the decision for each of these three Navigation Location Support features can be made independently, eight different Navigation Location Support configurations are possible. Each of these eight configurations varies in price and performance, from the basic system which saves the most money but performs least effectively all the way to the elaborate system, which saves the least money but performs most effectively. Any one of these eight Navigation Location Support configurations may be selected.

Driver Input-Output Features

The Driver Input-Output concerns how the driver will tell the system the intended destination and how the system will tell the driver appropriate directions and instructions. With regard to **Driver Input-Output Features**, decisions for three features must be made. The first feature, **driver output format**, can be text/graphics output, or text and graphics plus voice output. The second feature, **driver input format**, involves either the driver entering text input information or having the option of entering text information plus menu selection. The third feature, **navigational map display**, can be track-up only (where the map display changes orientation so that the car symbol is always heading toward the top of the screen), or track-up, plus north-up map display option

(where the option exists to have the map display oriented with north at the top of the screen, regardless of the cars direction of travel).

The basic system, **Configuration 1**, uses text/graphics output, text input only, and the track-up only map display; whereas the elaborate system, **Configuration 8**, uses text and graphics plus voice output, text plus menu display input, and the track-up plus north-up map display option. Because the decision for each of these three Driver Input-Output Features can be made independently, eight different Driver Input-Output configurations are possible. Each of these eight configurations varies in price and performance, from the basic system which saves the most money but performs least effectively all the way to the elaborate system, which saves the least money but performs most effectively. Any one of these eight Driver Input-Output configurations may be selected.

Human Factors Expert

As the Human Factors Expert, you should use the following decision making strategy in your interactions with the Program Manager:

View the situation as a design problem in which your job is to attempt to play down the conflict nature of the task and view it as a problem to be solved. Naturally, you want to improve the performance of the system as much as you can, but you are also interested in saving money and thereby meeting the needs of the Program Manager.

Due to performance requirements it is crucial that 2000 piu's are gained in the development of the Automobile Navigation System project. Any additional performance improvements units (piu's) that can be gained would prove beneficial to both you and to the consumers of the product that you are developing.

Visual Display Hardware

Display Configuration	Display Resolution	Display Size	Display Colors	Performance Units Gained
1	Medium	8 inch	16 colors	0 piu
2	Medium	8 inch	256 colors	100 piu
3	Medium	10 inch	16 colors	200 piu
4	Medium	10 inch	256 colors	300 piu
5	High	8 inch	16 colors	400 piu
6	High	8 inch	256 colors	500 piu
7	High	10 inch	16 colors	600 piu
8	High	10 inch	256 colors	700 piu

piu = performance improvement units

Navigation Location Support

Navigation Configuration	Antennae Coverage	Error-checking Capability	Level of Database Detail	Performance Units Gained
1	Moderate	Normal	Standard	0 piu
2	Moderate	Normal	Extended	150 piu
3	Moderate	Enhanced	Standard	300 piu
4	Moderate	Enhanced	Extended	450 piu
5	High	Normal	Standard	600 piu
6	High	Normal	Extended	750 piu
7	High	Enhanced	Standard	900 piu
8	High	Enhanced	Extended	1050 piu

piu = performance improvement units

Driver Input/Output Features

Input/Output Configuration	User Output Format	User Input Format	Navigational Map Display	Performance Units Gained
1	Text/Graphic	Text Input	Track-Up Only	0 piu
2	Text/Graphic	Text Input	Plus North-Up	250 piu
3	Text/Graphic	Plus Menu	Track-Up Only	500 piu
4	Text/Graphic	Plus Menu	Plus North-Up	750 piu
5	Plus Voice	Text Input	Track-Up Only	1000 piu
6	Plus Voice	Text Input	Plus North-Up	1250 piu
7	Plus Voice	Plus Menu	Track-Up Only	1500 piu
8	Plus Voice	Plus Menu	Plus North-Up	1750 piu

piu = performance improvement units

Appendix C

TRACE Design Contract

Automobile Navigation System Design Contract

Visual Display Hardware			
Display Configuration	**Display Resolution**	**Display Size**	**Display Colors**
	Medium	8 inch	16 colors
Number ____	High	10 inch	256 colors
	(circle one)	(circle one)	(circle one)

Navigation Location Support			
Navigation Configuration	**Antennae Coverage**	**Error-checking Capability**	**Level of Database Detail**
	Moderate	Normal	Standard
Number ____	High	Enhanced	Extended
	(circle one)	(circle one)	(circle one)

Driver Input/Output Features			
Input/Output Configuration	**User Output Format**	**User Input Format**	**Navigational Map Display**
	Text/Graphic	Text Input	Track-Up Only
Number ____	Plus Voice	Plus Menu	Plus North-Up
	(circle one)	(circle one)	(circle one)

Program Manager:

____

Initials - Date

Human Factors Expert:

____

Initials - Date

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